STATUS OF RADIO-FREQUENCY (RF) DEFLECTORS AT RADIABEAM

L. Faillace#, R. Agustsson, J. Hartzell, A. Murokh, S. Storms
RadiaBeam Technologies, 1717 Stewart St, Santa Monica CA, USA

Abstract

Radiabeam Technologies recently developed an S-Band normal-conducting Radio-Frequency (NCRF) deflecting cavity for the Pohang Accelerator Laboratory (PAL) in order to perform longitudinal characterization of the sub-picosecond ultra-relativistic electron beams. The device is optimized for the 135 MeV electron beam parameters. The 1m-long PAL deflector is designed to operate at 2.856 GHz and features short filling time and femtosecond resolution. At the end of 2012, we delivered an X-band Traveling wave RF Deflector (XTD) to the ATF facility at Brookhaven National Lab. The device is optimized for the 100 MeV electron beam parameters at the Accelerator Test Facility (ATF) at Brookhaven National Laboratory, and is scalable to higher energies. The XTD is designed to operate at 11.424 GHz, and features short filling time, femtosecond resolution, and a small footprint. The XTD is currently being assembled at ATF for high-power operation and conditioning results will be reported soon.

INTRODUCTION

Some of the most compelling and demanding applications in high-energy electron beam-based physics, such as linear colliders [1], X-ray free-electron lasers [2], inverse Compton scattering (ICS) sources [3,4], and excitation of wakefields in plasma for future high energy physics accelerators [5,6] now require sub-picosecond pulses. Thus, improvement in resolution and capabilities of fast longitudinal diagnostics is needed.

RadiaBeam has recently developed and delivered an S-Band Traveling wave Deflecting mode cavity to be utilized for direct longitudinal phase space measurements of compressed electron beams at the Pohang Accelerator Laboratory X-ray SASE-FEL [7] as well an X-band deflector for BNL-ATF. Both deflectors take advantage of the well-established cell machining in S-Band as well as our version of the SLAC-modified procedure for surface preparation for high RF power operation.

RF/THERMAL DESIGN

PAL Deflector Design

The 3D RF design was performed with HFSS [8]. The PAL deflector is a disc-loaded traveling-wave (TW) structure operating in the TM_{11} mode at 2.856 GHz. Two coupler cells allow the input and output of the RF power provided by a standard WR284 metallic waveguide.

The main deflecting cells, stacked in between the couplers, have a pillbox-like shape, each with holes located perpendicular to the deflection plane for the separation of the two dipole-mode field polarizations. The cell-to-cell phase shift is 120 degrees. The final full PAL deflector consists of an overall number (couplers plus main cells) of 28 cells. The main RF parameters for the L=1m long PAL deflector is listed in Table 1. The total deflecting voltage is equal to 8.5 MV, assuming an input RF power value of 10MW. Very good agreement was found between the simulated and the measured values.

Table 1: PAL Deflector RF Parameters.

RF Parameter	Value
2π/3-mode frequency f	2.856 GHz
Transverse Shunt Impedance r_T	28.7 MΩ/m
Unloaded Q	13,400
Attenuation α	0.15 m^{-1}
Group Velocity v_g	0.014 c
Kick/√Power	2.7 MeV/√MW
Length L	1 m

Thermal simulations were carried out with Ansys [9]. We only inserted a cooling channels system, very compact, for frequency/temperature stabilization. The result shown in Figure 1 refers to the case of an average RF power of 1kW. Due to the low temperature gradient (<3deg) across the structure, no internal channels were necessary.

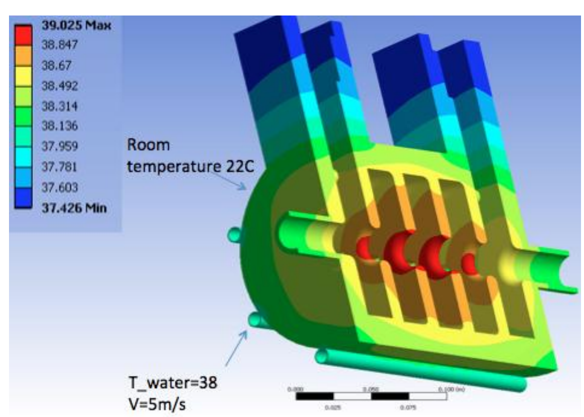


Figure 1: Thermal simulation of the PAL deflector model for 1kW average RF power.

faillace@radiabeam.com

XTD Deflector Design

The 3D RF design was performed with HFSS. The final design parameters are shown in Table 2.

Table 2: XTD Deflector RF Parameters.

Parameter	Value
Field amplitude, $\sqrt{E/P^{1/2}}$	8.48 kV/m/W$^{1/2}$
Group velocity, v_g	0.0267c
Attenuation factor, α	0.66 m^{-1}
Cavity length, L_T	0.40 m
Number of cells, N	45

TUNING AND INITIAL BEAM MEASUREMENTS

PAL Deflector

Figure 2: Picture of the PAL deflector after the final brazing and before installation.

The PAL deflector after final brazing and before installation is shown in Figure 2.

We measured the coupling coefficients at both ports, S11= -40dB (RF input port) and S22= -32dB with a SWR<1.05 for both ports. The deflector cells were tuned to the spec (<±2°), at 22C and under nitrogen flow, by using the nodal shift procedure (plunger method). From bead-pull measurements, we obtained the "flower"-like manifold that is plotted in Figure 3 showing a perfectly tuned 2π/3 operating mode.

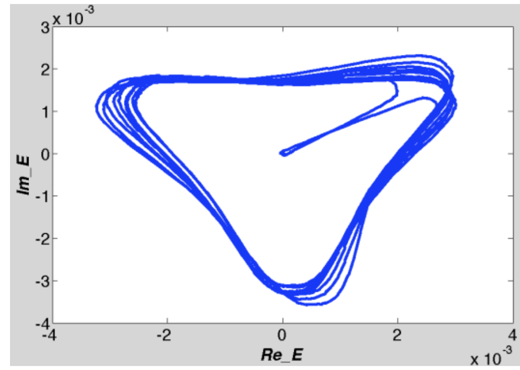


Figure 3: Polar plot of the on-axis electric field.

The bead-pull measurement (off-axis) of the electric field profile after final tuning is given in Figure 4.

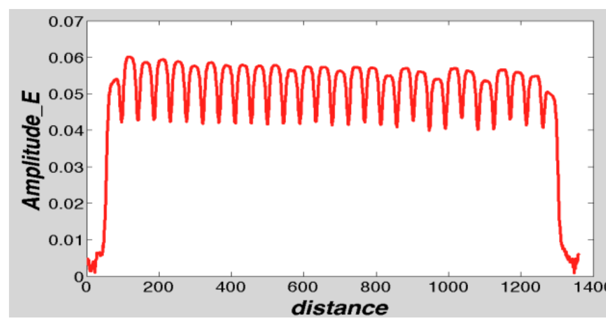
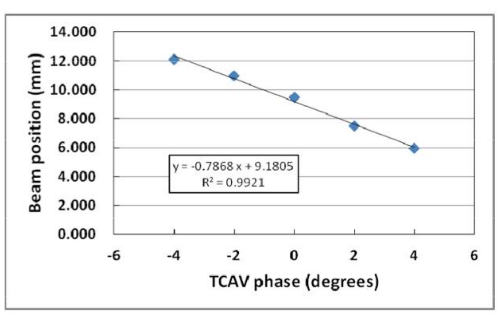
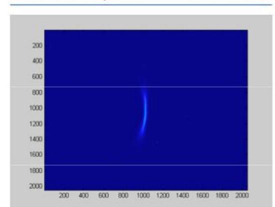


Figure 4: Off-axis electric field measurement (bead-pull).

After RF conditioning, initial beam length measurements were performed in August (see Figure 5). Only a fraction of MW of RF power was required at the moment for the resolution of their 200pC, 85.6 MeV beam.



parameter	value
Laser inj. ph.	35 °
Beam energy	85.6 MeV
Beam charge	200 pC
TCAV RF power	0.137 MW



TCAV phase (degrees)	CM in Y (pixel)	beam position in Y (mm)	beam size in Y (μm)
4	716	5.943	1268.55
2	901.2	7.480	1267.40
0	1139.7	9.460	1238.08
-2	1317.9	10.939	1226.97
-4	1455.6	12.081	1262.24

(rms bunch length)
~ 1.53 ps
~ 0.456 mm
~ 1.57 degS

Figure 5: Low-power initial beam diagnostics at PAL by using the deflector delivered by RadiaBeam.

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XTD Deflector

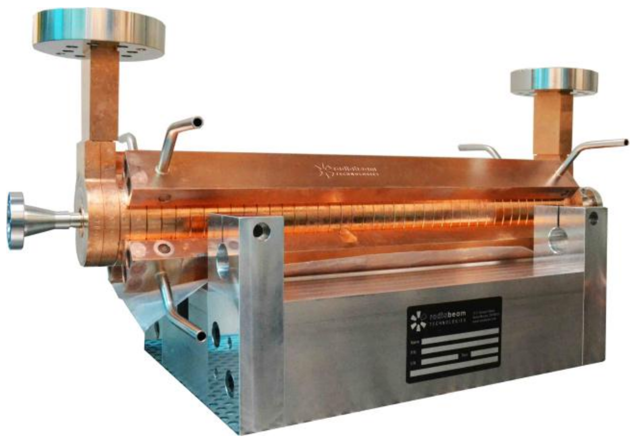

Figure 6: Picture of the XTD deflector after the final brazing and before installation.

The XTD deflector after final brazing and before installation is shown in Figure 6.

The on-axis electric field profile and phase, measured after the tuning, are plotted in Figure 7. The electric field peaks are located at the iris positions, as expected from the measurement using a small dielectric bead. The slope in the peaks is due to the field attenuation along the structure, as expected from a constant-impedance cavity, but taking this factor into account the flatness is <1%. Also, the phase of the field presents the correct monotonic behavior with an average value of 120degrees. The polar plot of the reflection coefficient at port 2 (S22) is shown in Figure 8.

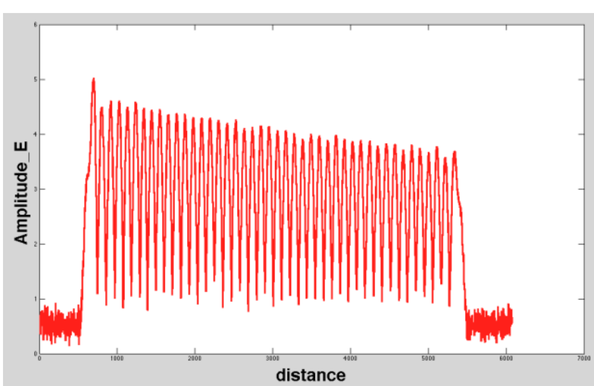

Figure 7: Electric field [a.u.] measured along the axis [step number] after tuning.

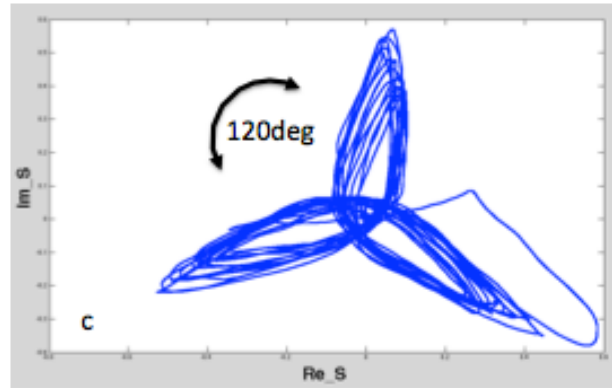

Figure 8: Polar plot of the S22 (real and imaginary part), before tuning.

CONCLUSIONS

RadiaBeam Technologies has successfully completed design, fabrication, brazing and validation of an S-Band deflector for the Pohang Accelerator Laboratory (PAL) X-FEL and an X-band deflector for the BNL-ATF facility. Upon delivery to PAL and conditioning, promising and satisfactory initial beam length measurements were carried out. The XTD deflector was delivered in 2012 and it is now under installation.

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